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Factory Control System

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BEng Electrical and Electronic Engineering Year 3

2024 / 2025

Applied Programmable Logic Controllers ACDA6000

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Introduction

This report details the process of designing a factory control system using Factory I/O software which sorts 4 different packages on a conveyor belt based on their size and weight using a variety of different components such as sensors and pushers to replicate a real-world factory. The report also contains details of the ladder logic program used to operate the various functions in the factory using Siemens PLC simulation software called TIA Portal, as well as an HMI (Human Machine Interface) system which facilitates operator interaction of the factory operations remotely, just as a real factory operator would if there were problems with the conveyor.

Main Body

Task 1 – Brief PLC Literature Review

Programmable Logic Controllers (PLCs) are industrial computers used for automation of manufacturing processes, such as assembly lines, machinery operation, and other factory or plant processes. The most common PLCs in use today are manufactured by many different brands and the market for them is fairly wide considering most have only ever heard of one or two of them. A few examples of these PLCs are as follows:

- Siemens SIMATIC PLCs [1].

Siemens is renowned for its SIMATIC series, particularly the S7 family, which includes models such as the S7-1200, S7-1500, and S7-300. These PLCs are widely used in Europe and globally in various industries, including automotive and process automation. The S7-1500 has more advanced customisation, as the technology is more advanced. This PLC is highly reliable, with excellent durability in industrial settings. It also can be used in many product lines scaling from the smallest operations to even the larger-scale applications. Siemens also has the TIA Portal software which can be used for PLC programming, HMI design, and network configuration all in one application.

- Allen-Bradley PLCs [2].

Allen-Bradley is a highly prevalent company in North America, and its ControlLogix and CompactLogix series of PLCs are used in large-scale and mid-sized automation, respectively. The ControlLogix PLCs have an especially solid performance when working with production lines, with its high processing power and compatibility with other industrial devices. The ControlLogix series also have their own software similarly to Siemens called Studio 500 Logix Designer. This software is used for programming the PLCs and offers a user-friendly programming environment with its simplicity and easy-to-learn mechanics.

- Mitsubishi Electric PLCs [3].

Mitsubishi Electric also produces their own PLCs, namely the **MELSEC** series, which are widely used in Asia and are also steadily growing in other markets around the world. These PLCs are popular in manufacturing, packaging, and automotive industries because of their pricing which is competitive in comparison to other PLCs on the market. They also have convenient integration when it comes to other Mitsubishi products, such as their robotics automation products. These PLCs have decently well-performing speeds and are also strong when it comes to high-speed motion controlling applications.

A PLC comparison table can be seen below with the pros and cons of each of the PLCs discussed in a more concise format.

Brand	Pros	Cons
Siemens	• Suitable for projects of varying sizes • Durable • Integrated software in the form of TIA Portal	• High cost • Steep learning curve for TIA Portal software
Allen-Bradley	• User-friendly custom software • high performance speeds	• High cost • Limited global reach

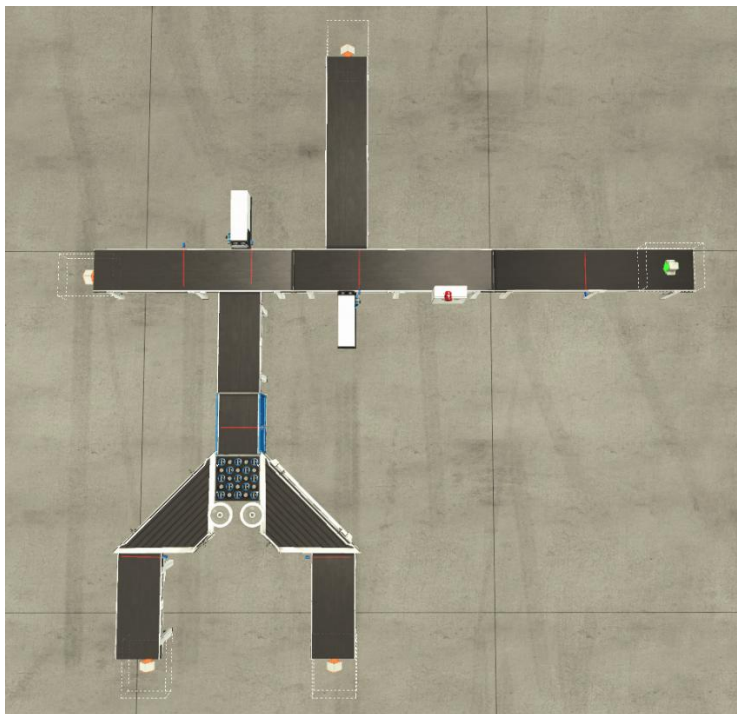
Mitsubishi	• Competitive pricing • Compact design • Useful for Mitsubishi products	• Less intuitive software • Limited global reach
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Task 2 – Factory I/O Sorting Process Design

As stated previously, the Factory I/O design sorts 4 different sized boxes in terms of weight and size. This is done in various ways using a multitude of different components available in the application. The list of components used in the factory simulation are as follows:

- 7 conveyor belts
- 2 conveyor belt spurs
- 1 conveyor scale
- 1 pop-up wheel sorter
- 7 diffuse sensors
- 2 pushers
- 1 start button
- 1 stop button
- 1 siren
- 1 digital display

Below is a top-down image of the factory which was created in Factory I/O to display all of the components which were used.



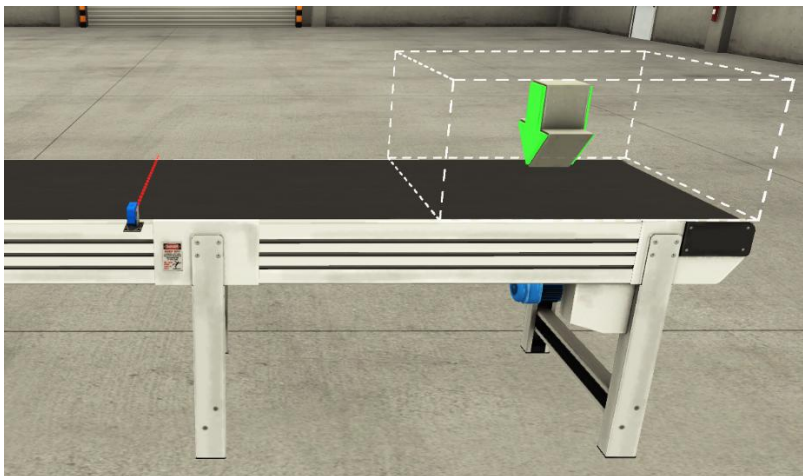
The factory process begins on the right of the image and continues left until each of the different boxes are sorted onto different conveyor belts and sent to different ends of the conveyor.

The factory also has an electrical box attached with the buttons that can manually control the operation of the conveyor, an image of which can be seen below.



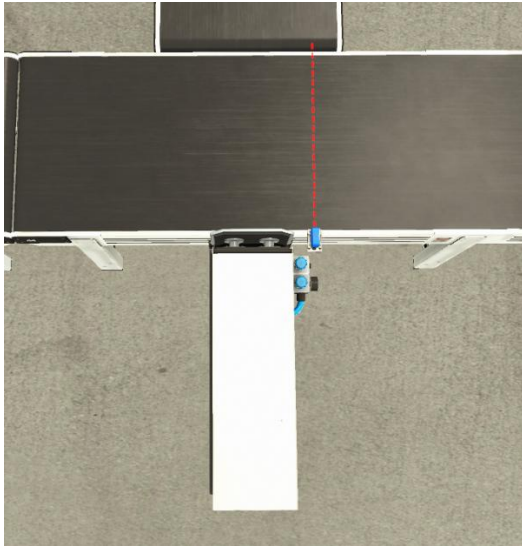
The electrical box has 2 buttons attached to it, one being the green start button which starts the whole operation of the conveyor, and the red stop light which stops the operations. There is also a siren attached which sounds to alert the operator when the factory process begins.

The image below displays a closer look at the beginning of the conveyor belt.



Here is the beginning of the conveyor belt, where a green arrow called an emitter can be seen which emits the 4 different sized boxes (being small, medium, large and palletizing boxes, or extra small) in intervals of 2-4 seconds. These boxes are then transported along the conveyor belts, passing by diff sensors placed at various heights above the conveyor belts. The reason for the sensors being placed at different heights is because this is a simple way to differentiate the some of the boxes from each other as they are different sizes and heights.

A closer example of one of the diff sensors can be seen in the image below.



This particular sensor is for sorting the large-sized boxes from the rest. The sensor is placed at a height where only the large boxes are detected, and the sensor then activates a pusher that pushes the large boxes onto another conveyor belt going in a different direction.

When looking at the top-down image of the conveyor, a second pusher can be seen which is used to sort the small and medium boxes from the palletizing boxes. This is done by placing another diff sensor placed at a height which detects the small and medium boxes but not the palletizing ones, as the palletizing boxes are slightly smaller in height to the others.

One issue with the method of differentiating different boxes by their height is that the small and medium boxes are both the same height, therefore another method must be used to differentiate them. There are two differences between the small and medium boxes, being their width and their weight. In this factory process, a conveyor scale has been used which weighs the boxes as they move onto the scale.

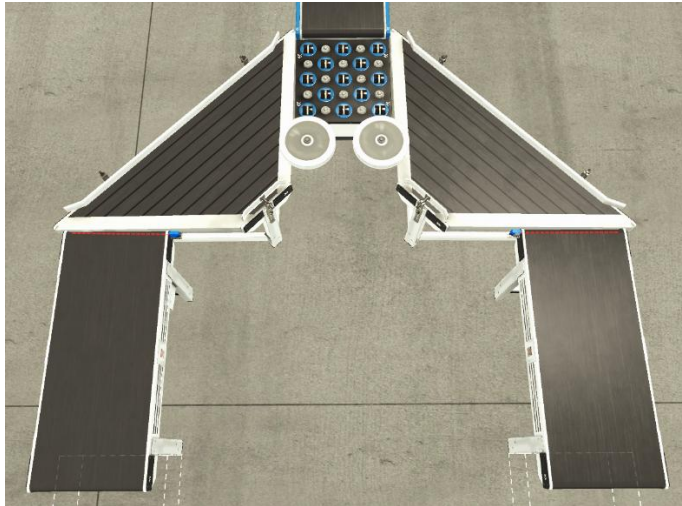
Below is an image which displays the conveyor scale.



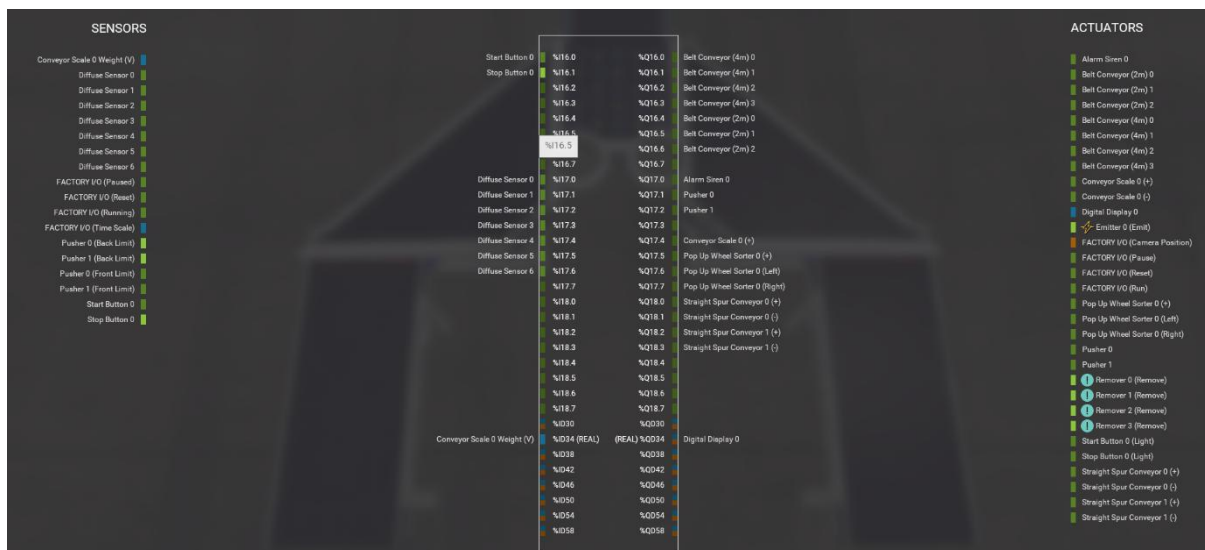
The conveyor scale weighs items which pass over it, and a display is placed on the scale to visualise the weight of the boxes when they go over the scale, although the conveyor moves the boxes so fast that the scale may struggle to give an accurate reading of the weight. To avoid this, a sensor is placed above which stops the conveyor scale belt on a timer and continues once the timer is done.

After the conveyor scale there is a pop-up wheel sorter which can transition from left to right which is used to sort the small and medium boxes onto different conveyors. The conveyor scale communicates

Below is an image of the pop-up wheel sorter and the branching conveyors paths.



The final requirement of the Factory I/O project before moving on to the ladder logic design is the drivers. The drivers are where the components get linked to a simulation of a PLC, as can be seen in the image below.



The left of the PLC contains all of the inputs of the system, such as buttons and sensors, meanwhile the right of the PLC has all of the outputs, being the conveyor belts, siren, and pushers.

Task 3 – PLC Factory Process Ladder Logic

The ladder logic for the factory was created in the TIA Portal software, which is a Siemens software for designing operations for PLCs. The Factory I/O conveyor was connected to a simulation of a PLC through the drivers of the factory to emulate a real PLC being connected to a production line.

PLC Tag Table

The PLC process begins with a tag table, which contains the tags for each component and operation of the PLC. Tags are a form of label which indicates the component name and type of data or address the component has. A PLC tag table is required for every PLC for them to work, as without tags, it isn't possible to assign the operations to a component and therefore the code will not be able to run. A good example of this would be assigning a switch as an input which connects to an LED as an output in the ladder logic, so that when pressing that switch the LED will turn on. In the tag table, the switch would be assigned to I 0.0 to indicate it being the first input and the LED would be Q 0.0 for the output. To set multiple inputs or outputs, you would go from 0.0 to 0.1 to 0.2 and so on, however it is easier to group components which are the same type, such as buttons or sensors, with a different first number, meaning two buttons would be I 0.0 and I 0.1, and the sensors would be set to the address I 1.0 and I 1.1.

Below is the tag table for the components of the factory ladder logic.

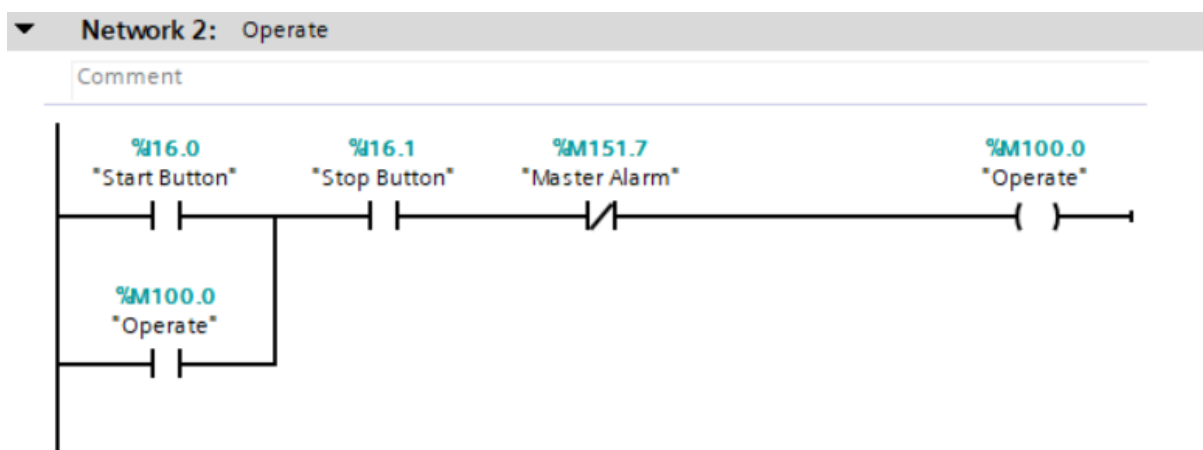
PLC tags									
	Name	Tag table	Data type	Address ▲	Retain	Acces...	Writa...	Visibl...	Comment
1	Start Button	Default tag table	Bool	%I16.0	☐	☒	☒	☒	
2	Stop Button	Default tag table	Bool	%I16.1	☐	☒	☒	☒	
3	Diff Sensor 0	Default tag table	Bool	%I17.0	☐	☒	☒	☒	
4	Diff Sensor 1	Default tag table	Bool	%I17.1	☐	☒	☒	☒	
5	Diff Sensor 2	Default tag table	Bool	%I17.2	☐	☒	☒	☒	
6	Diff Sensor 3	Default tag table	Bool	%I17.3	☐	☒	☒	☒	
7	Diff Sensor 4	Default tag table	Bool	%I17.4	☐	☒	☒	☒	
8	Diff Sensor 5	Default tag table	Bool	%I17.5	☐	☒	☒	☒	
9	Diff Sensor 6	Default tag table	Bool	%I17.6	☐	☒	☒	☒	
10	Weight	Default tag table	Real	%ID34	☐	☒	☒	☒	
11	Conveyor 0	Default tag table	Bool	%Q16.0	☐	☒	☒	☒	
12	Conveyor 1	Default tag table	Bool	%Q16.1	☐	☒	☒	☒	
13	Conveyor 2	Default tag table	Bool	%Q16.2	☐	☒	☒	☒	
14	Conveyor 3	Default tag table	Bool	%Q16.3	☐	☒	☒	☒	
15	Conveyor 4.2	Default tag table	Bool	%Q16.4	☐	☒	☒	☒	
16	Conveyor 5.2	Default tag table	Bool	%Q16.5	☐	☒	☒	☒	
17	Conveyor 6.2	Default tag table	Bool	%Q16.6	☐	☒	☒	☒	
18	Siren	Default tag table	Bool	%Q17.0	☐	☒	☒	☒	
19	Pusher 0	Default tag table	Bool	%Q17.1	☐	☒	☒	☒	
20	Pusher 1	Default tag table	Bool	%Q17.2	☐	☒	☒	☒	
21	Conveyor Scale 0+	Default tag table	Bool	%Q17.4	☐	☒	☒	☒	
22	Wheel Sorter 0+	Default tag table	Bool	%Q17.5	☐	☒	☒	☒	
23	Wheel Sorter 0 Left	Default tag table	Bool	%Q17.6	☐	☒	☒	☒	
24	Wheel Sorter 0 Right	Default tag table	Bool	%Q17.7	☐	☒	☒	☒	
25	Conveyor Spur 0+	Default tag table	Bool	%Q18.0	☐	☒	☒	☒	
26	Conveyor Spur 0-	Default tag table	Bool	%Q18.1	☐	☒	☒	☒	
27	Conveyor Spur 1+	Default tag table	Bool	%Q18.2	☐	☒	☒	☒	
28	Conveyor Spur 1-	Default tag table	Bool	%Q18.3	☐	☒	☒	☒	
29	display	Default tag table	Real	%QD34	☐	☒	☒	☒	
30	Operate	Default tag table	Bool	%M100.0	☐	☒	☒	☒	

PLC tags									
	Name	Tag table	Data type	Address ▲	Retain	Acces...	Writa...	Visibl...	Comment
31	Scale Control	Default tag table	Bool	%M100.1	☐	☒	☒	☒	
32	BoxLoaded	Default tag table	Bool	%M100.2	☐	☒	☒	☒	
33	Ready	Default tag table	Bool	%M100.3	☐	☒	☒	☒	
34	Warning	Default tag table	Byte	%MB150	☐	☒	☒	☒	
35	Warning 0	Default tag table	Bool	%M150.0	☐	☒	☒	☒	
36	Warning 1	Default tag table	Bool	%M150.1	☐	☒	☒	☒	
37	Warning 2	Default tag table	Bool	%M150.2	☐	☒	☒	☒	
38	Warning 3	Default tag table	Bool	%M150.3	☐	☒	☒	☒	
39	Warning 4	Default tag table	Bool	%M150.4	☐	☒	☒	☒	
40	Warning 5	Default tag table	Bool	%M150.5	☐	☒	☒	☒	
41	Warning 6	Default tag table	Bool	%M150.6	☐	☒	☒	☒	
42	Warning 7	Default tag table	Bool	%M150.7	☐	☒	☒	☒	
43	Alarms	Default tag table	Byte	%MB151	☐	☒	☒	☒	
44	Alarm 0	Default tag table	Bool	%M151.0	☐	☒	☒	☒	
45	Alarm 1	Default tag table	Bool	%M151.1	☐	☒	☒	☒	
46	Alarm 2	Default tag table	Bool	%M151.2	☐	☒	☒	☒	
47	Alarm 3	Default tag table	Bool	%M151.3	☐	☒	☒	☒	
48	Alarm 4	Default tag table	Bool	%M151.4	☐	☒	☒	☒	
49	Alarm 5	Default tag table	Bool	%M151.5	☐	☒	☒	☒	
50	Alarm 6	Default tag table	Bool	%M151.6	☐	☒	☒	☒	
51	Master Alarm	Default tag table	Bool	%M151.7	☐	☒	☒	☒	
52	Master Counter	Default tag table	UInt	%MW200	☐	☒	☒	☒	
53	Large Box Counter	Default tag table	UInt	%MW202	☐	☒	☒	☒	
54	Small Box Counter	Default tag table	UInt	%MW204	☐	☒	☒	☒	
55	Medium Box Counter	Default tag table	UInt	%MW206	☐	☒	☒	☒	
56	Palletizing Box Counter	Default tag table	UInt	%MW208	☐	☒	☒	☒	
57	Ready Weight	Default tag table	Real	%MD300	☐	☒	☒	☒	
58	disp weight	Default tag table	Real	%MD304	☐	☒	☒	☒	

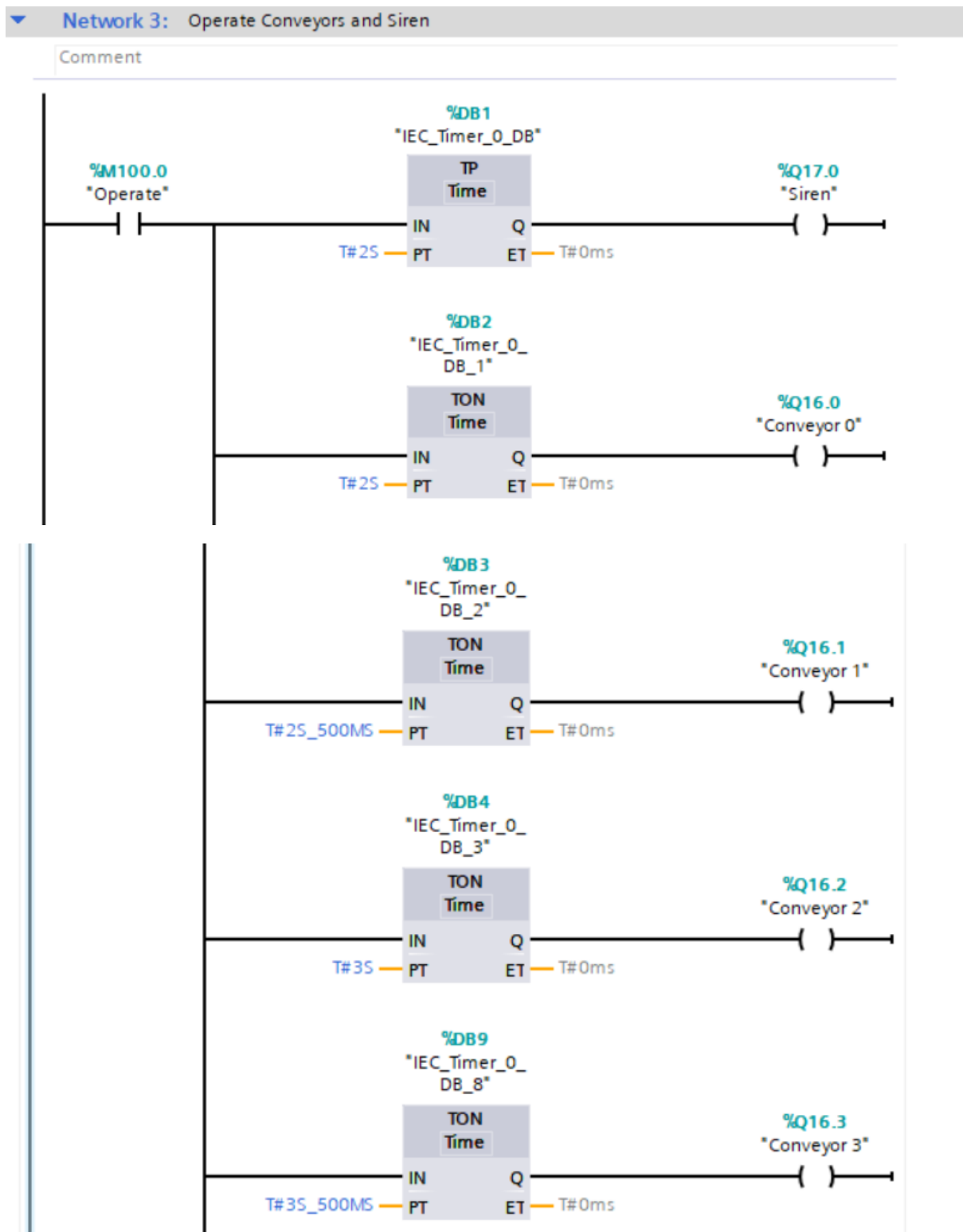
As previously stated, when looking at the address of a tag, I in a tag table stands for input and Q stands for output. M is for memory functions such as the weighing scale control. The addresses for these components are deliberately chosen based on where they have been linked to in the drivers of the Factory/IO project.

PLC Networks / Ladder Logic

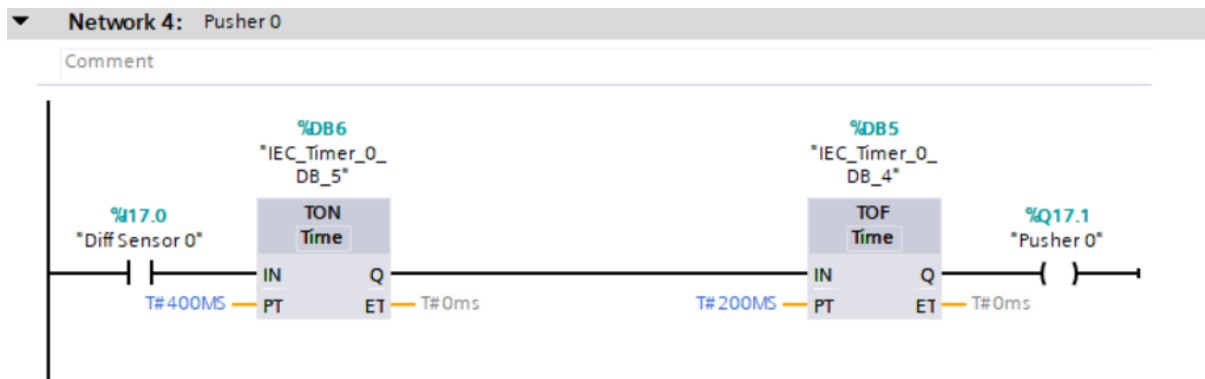
Below are screenshots of the various networks which create the ladder logic for the factory conveyor. Network 1 is missing as it is just a basic network containing the function for simulating the PLC with Factory I/O.



Network 2 is the operate network which controls the starting and stopping of the factory operations, turning it on and off. The start button is pressed which signals the operations to start, with a stop button which stops the operations when pressed. There is a normally closed input labelled master alarm, meaning that when the master alarm has gone off, the operation stops also.



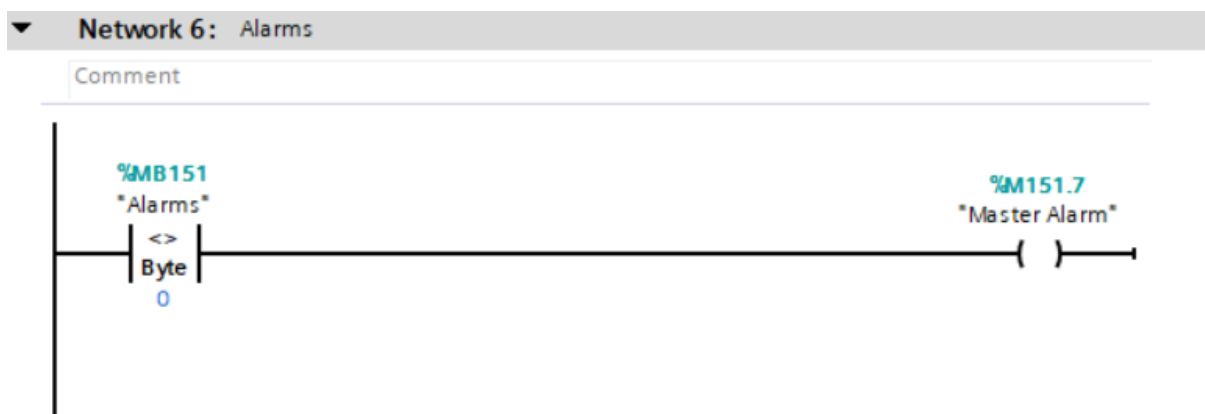
Network 3 is for operating the conveyors. When the start button is pressed and the operations begin, a siren sounds for 2 seconds using a timer operation, and after the siren stops sounding the conveyors begin to operate in sequence, being activated one after the other every half second. The reason for the conveyors starting in sequence rather than all at once is to limit the current being drawn at the start of the system.



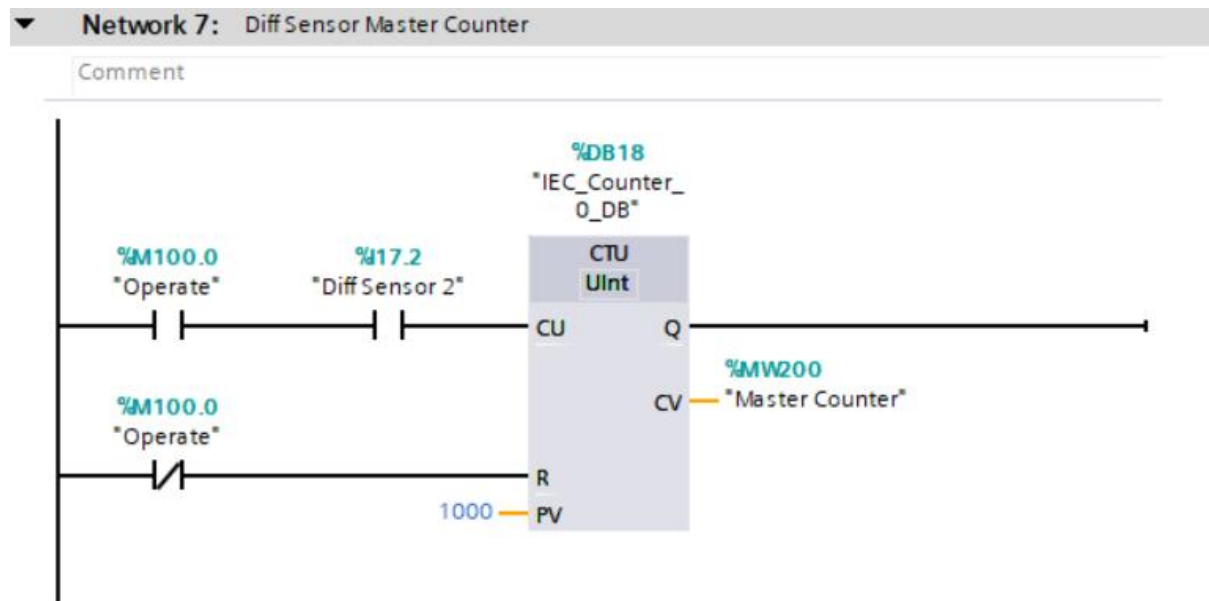
Network 4 is for operating the pusher for the large boxes. Once a large box has passed the sensor, a timer begins which signifies the amount of time the box takes to reach the pusher after breaking the beam of the sensor, which in this case is 400 milliseconds. The pusher is then activated once the timer is complete. Without another timer to tell the pusher to deactivate, it will be stuck in the pushed-out position, therefore an off timer is placed by the pusher which deactivates the pusher after 200 milliseconds.



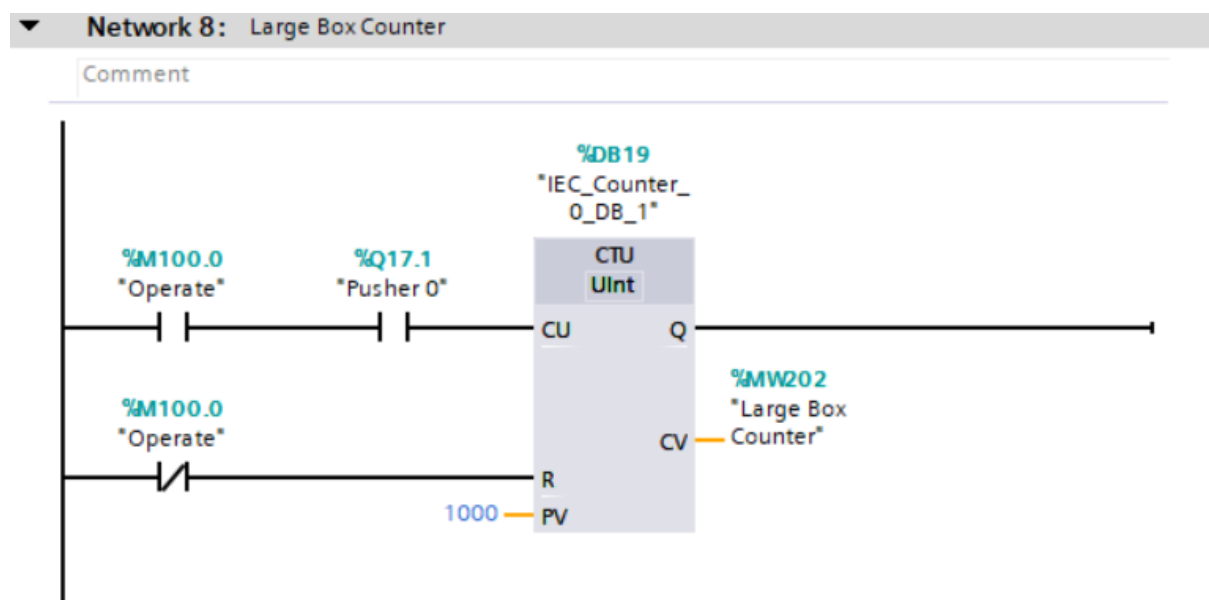
Network 5 is for the operation of the small and medium box pusher. As with the pusher for the large boxes, a sensor is placed which the boxes need to pass which indicates if they are small and medium boxes, and then a timer is activated to tell the pusher when to push the boxes.



Network 6 is for the operation of the alarms. When any of the alarms go off, the master alarm is then activated, which stops all operations of the factory conveyor.



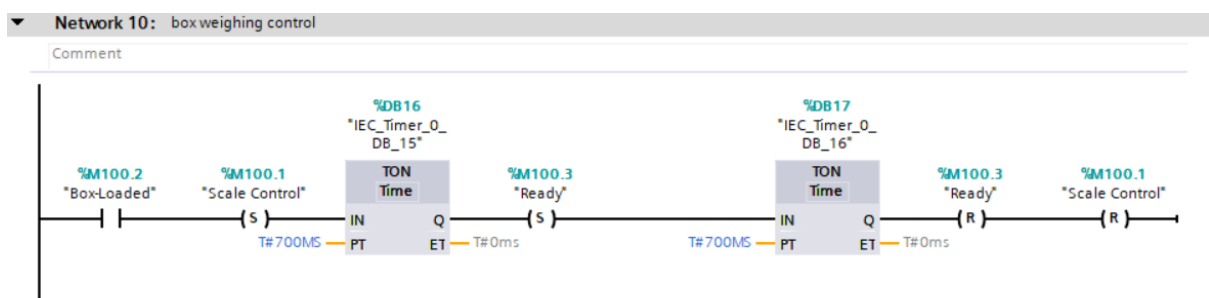
Network 7 is the operation for the master counter, which is utilised later when designing the HMI screens. A sensor is placed at the beginning of the conveyor which counts every box that passes, memorising the number of boxes which have passed the sensor, and the counter is reset when the conveyor operations are stopped.



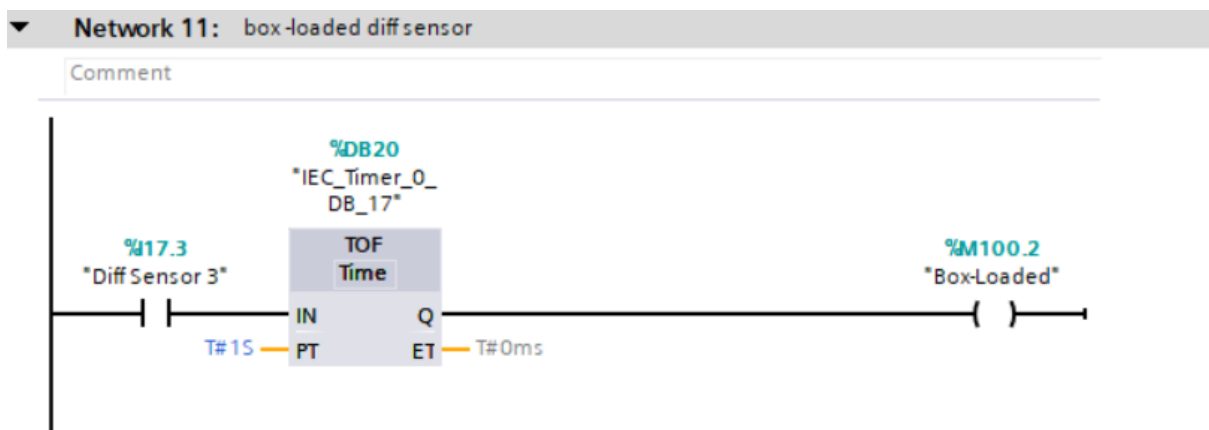
Network 8 is for the large box counter, and is extremely similar to the master counter, although only counts the large boxes instead. The counter is connected to pusher 0, which is the pusher for the large boxes, meaning the only boxes that will be counted are the ones that have been pushed by it. The sensor for the large boxes could also have been used instead of the pusher, although it makes no difference in the operations of the counter.



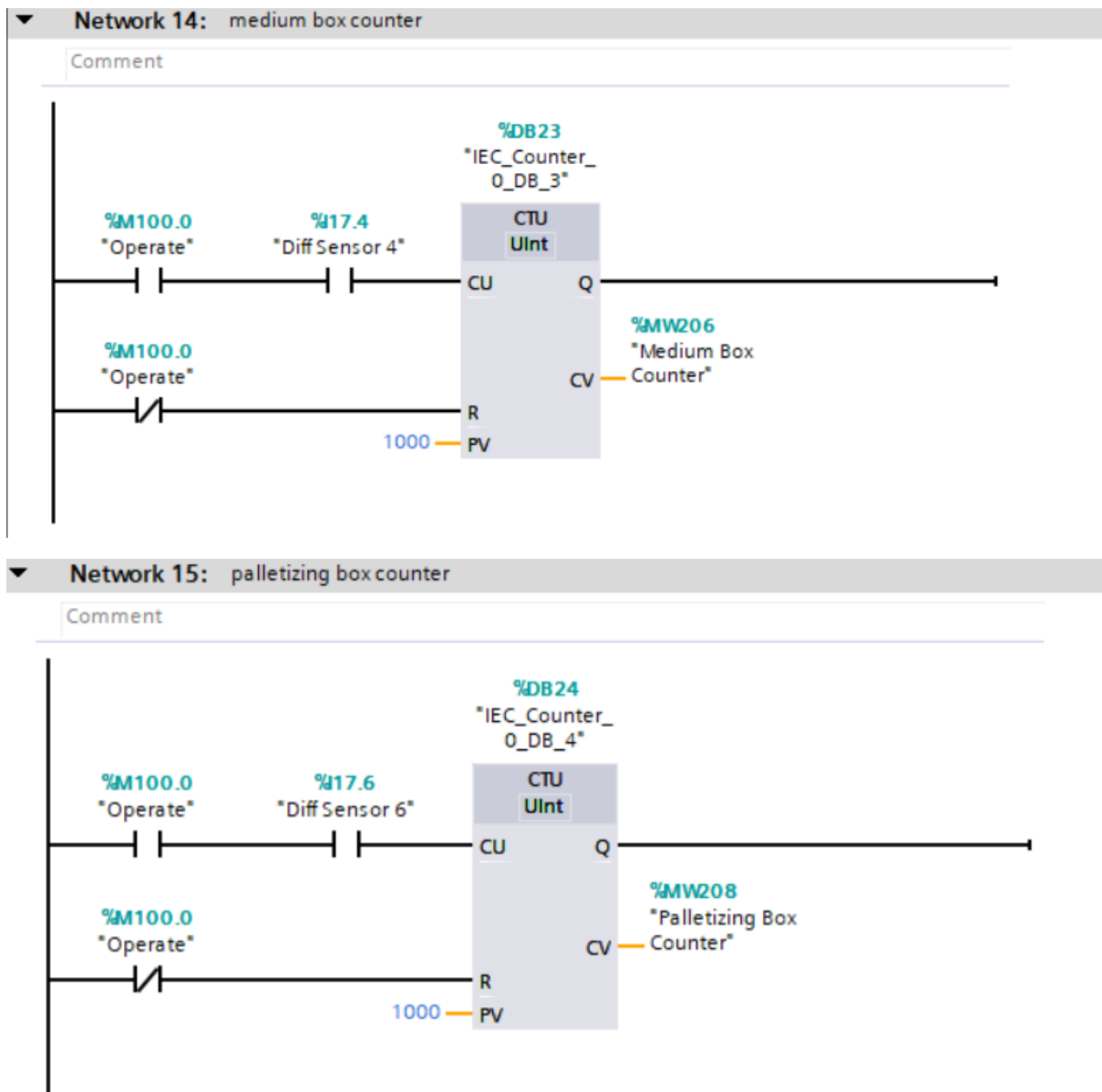
Network 9 is the operation for the conveyor scale control. When the operations have begun, the scale starts moving forwards as any other conveyor component would, although if the scale control memory is operating and there is a box detected on top of the scale, the scale will stop moving.



Network 10 is the network for operating the box weighing control. Once a box is loaded onto the conveyor scale, the scale control is activated and the conveyor scale stops moving to get an accurate measurement of the box weight, and there is also a timer which indicates the amount of time the box needs to sit on the scale before the scale starts moving again and weighing the next box.



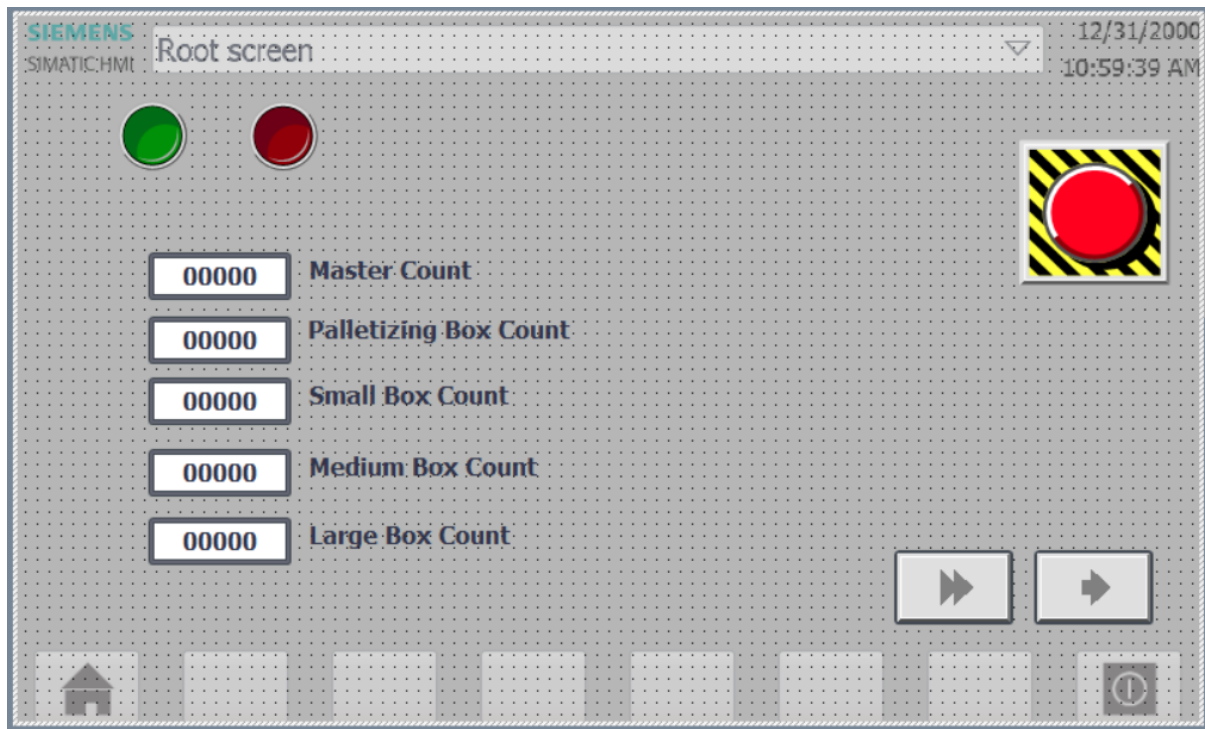
Network 11 is for the box-loaded sensor. When a box is loaded onto the conveyor, the conveyor does not stop moving, so a sensor is required to tell the conveyor scale to stop moving when a box has been loaded, and for this the sensor is placed directly on top of the scale.



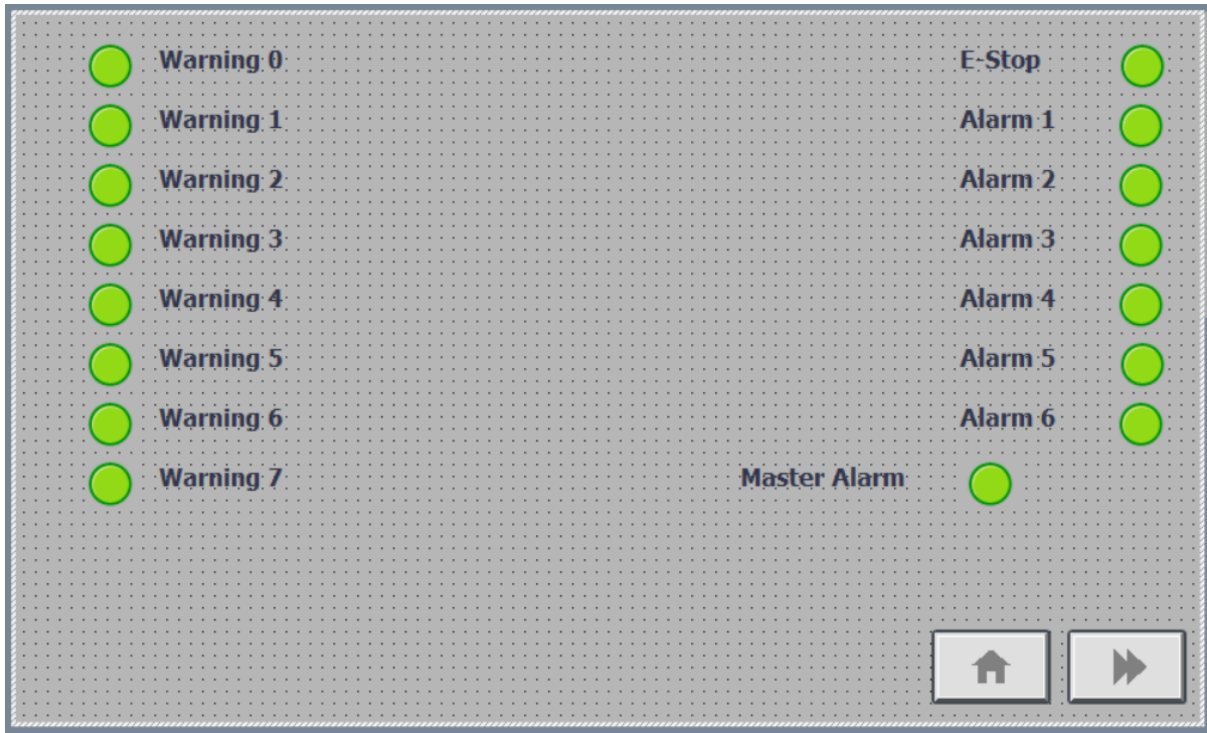
Networks 13, 14 and 15 are all counters for the boxes which haven't had counters created for them yet, these being the small, medium and palletizing boxes. For each of these counters, a sensor was placed at the end of their respective conveyor belts which all count the number of boxes that pass them. These networks work the same as the large box counter and will be seen when discussing the HMI device.

Task 4 – PLC HMI Device Design

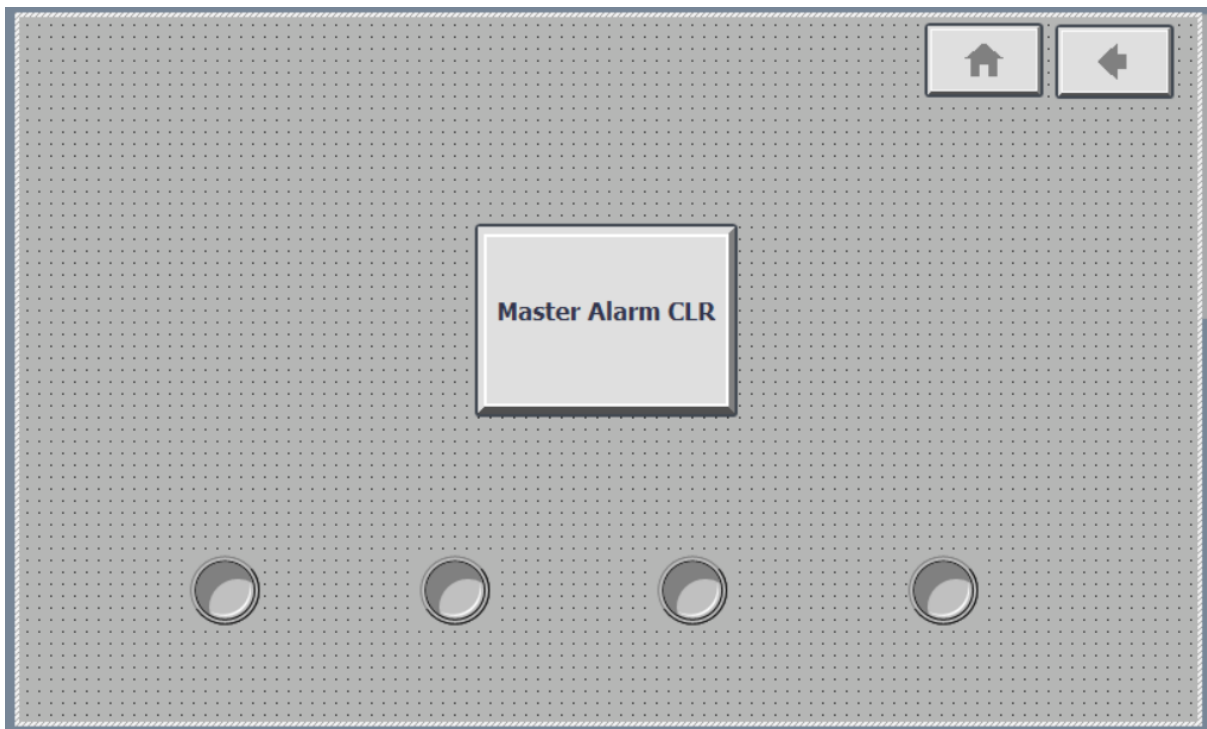
A HMI device has also been designed for an operator to interact with the operations of the factory conveyor. Three screens were made for the HMI, being the root screen, error screen and engineer screen.



The above diagram is of the root screen, or the home screen. There is a start button and a stop button, both of which connect to the operate tag and network for the whole system. There is also an emergency stop button which activates warnings on the error screen, causing the master alarm to activate and stop the whole operations. Below the start and stop buttons are the various counters mentioned previously, one for each of the different-sized boxes as well as a master counter for the total number of boxes that have been sent through the conveyor. The final two buttons in the bottom right are to navigate the different HMI screens.



Above is the error screen. If any of these warnings are activated by turning red, alarms will also activate, and the operations will halt. There is also a light for the emergency stop to indicate whether the system has stopped because of an error or because the operator has pressed the emergency stop button.



Above is the engineer screen. Each of these buttons deactivates a warning light and resets it, and the button in the middle clears the master alarm so that operations can begin again after the warnings have been fixed.

Conclusion

In conclusion, PLCs are efficient alternatives to operating factory lines and are widely used in many facilities today. There are a number of different PLC manufacturers, and each PLC serves its own purpose.

PLCs are automated and can easily be tweaked and tested in simulation software like Factory I/O and TIA Portal before being applied in a professional setting making them extremely simple and convenient to operate. Another way of making the operations of the PLC easier is by implementing HMI devices to the system so that operators can remotely access all kinds of information and also control the operations at will.

Using Factory I/O can also help when learning how production lines in factories operate and how PLCs can interact with them in a simple way. The same can be said for TIA Portal, which has many more functions than just designing ladder logic for factory lines. It can be used for many different projects involving PLCs thanks to its comprehensive operations, and people can still learn new ways to create different operations for different systems.

References

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